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Study on Factors Affecting Evacuation Capability of a Fire-Protection Walk in Underground Buildings

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Abstract

To investigate the evacuation capability of a fire-protection walk in underground buildings, a typical fire district connected with a fire-protection walk and a stair was set. Evacuation time for 388 people escaping from the area was simulated numerically. Simulation results that the width of all exits in a fire district, the distance between exit of the fire district and the entrance of the stair leading to the out space (walking distance in a fire-protection evacuation walk), the width of the stairs have great effects on evacuation time when the width of the fire-protection evacuation walk was determined. The largest capacity of evacuation can be reached when the exit width is almost the same or wider than the width of the fire-protection evacuation walk. Set the stair and its doors as wide as the fire-protection evacuation walk and a reasonable walking length in a fire-protection walk can prevent forming congestions near these doors.

Keywords: evacuation capability, fire-protection evacuation walk, undergrounding buildings, affecting factors

1. Introduction

Fire-protection evacuation walk is the only safe way for people to evacuate from underground buildings with large space. So, it is very important to investigate the evacuation ability of fire-protection evacuation walks according to the characteristics of the building and the fire. To analyse the evacuation ability of an evacuation walk, it is very helpful to simulate human behaviours in a fire or an emergency situation. The first study on human behaviour of evacuation was presented by researchers in the USA. The research was placed extra emphasis on disaster investigation of survivors from the 1970s. Many investigative and statistical methods were used to research some non-adaptive behaviours, such as panic, return and conformist mentality. As the great improvement of technologies, especially the computing technology, more researches were carried on to simulate movement of one people or a group of people in a building with evacuation models after the 1980s[1-6]. Many research results were presented by using social force models[7-9], cellular automaton models[10-11] and lattice gas models[12-13]. Some models considered interaction effects caused by human and human, human and buildings and human and environments of the accident[14-15]. These effects are reflected in human's psychological, social relations and physiological.

Generally, the width of all exits in a fire district, the distance between exit of the fire district and the entrance of the stair leading to the out space (walking distance in a fire-protection evacuation walk), the width of the stairs and the fire-protection evacuation walk are important factors that can affect the evacuation ability of a fire-protection evacuation walk. In this paper, we set a typical fire district with one exit which is connected with a fire-protection walk. The software

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Pathfinder was used to simulated the require times for people leave the fire district and the fire-protection walk. During the simulation, values of variables mentioned above were adjusted to find out their effects on evacuation ability of the fire-protection walk.

2. Settings of evacuate scenario

2.1. The fire district and the fire-protection evacuation walk

To focus the research on effects of evacuation ability caused by the above factors mentioned above, only one fire district with one exit was set. This exit connects to a fire-protection evacuation walk. The exit of the fire district is located in the middle of the side wall of the fire district. The fire-protection evacuation walk is vertical to the side wall of the fire district. The width of the exit, the stair and the distance of the two doors can be changed during the simulation. The area of the fire district is $1000m^2$.

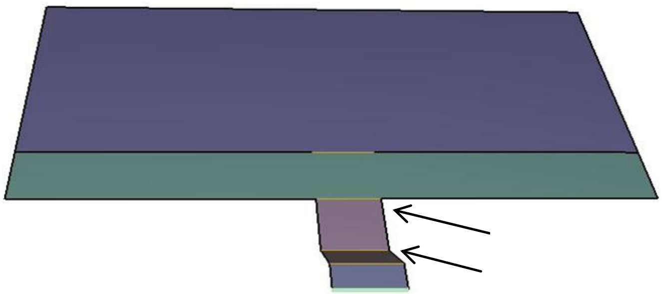

Fig. 1. Scenario of evacuation

To evacuate from the fire district, all of the people have to enter the fire-protection walk by walking through the exit, the fire-protection walk, the stair and the exit to out space, shown as Fig. 1. We do not change the width of the fire-protection evacuation walk in this study.

2.2. People in the fire district

There are 388 people in the fire district. The walking speed for male is 1 m/s and for female is 0.85 m/s. The number of different gender is set by the software randomly. Their initial positions in the fire district are also determined by the software randomly.

2.3. Other parameters

The width of the exit of the fire district, the distance between the exit of the fire district and the exit leading to the out space and the width of the stair are three key factors which affect the evacuation time greatly. In each simulation, only one factor was changed while other two factors kept constant. The values of these factors were chosen legitimately with consideration of rules of Chinese fire codes.

3. Simulation results

3.1. The width of the exit of the fire district

The exit of the fire district is the only way for people to escape from it when there is a fire. In this case, the distance between the exit of the fire district and the exit leading to the stair is 4m, the width of stair and the fire-protection evacuation walk is 3m and 4m respectively. The width of the exit of the fire district was set to 2 m, 2.4m, 2.8m, 3 m, 3.5 m, 4 m and 5 m.

Table 1. Evacuation time in simulations of different exit width

Exit width (*m*)	Evacuation time for the fire district (s)	Total evacuation time (s)
2	156	170.8
2.4	148.2	165.2
2.8	137.5	158.6
3	132.8	153.3
3.5	131.4	151.7
4	129	150.8
5	126	150.4

The required evacuation time were calculated by Pathfinder, as shown in Table 1. Obviously, the exit width of the fire district affects the evacuation time. As the simulation results show that when the width is small it costs more time for people to escape from it. But in this case, the evacuation time for the fire district and for the whole area almost no change when the width is greater than 3 meters. This means when the exit width of the fire district is equal to or greater than the width of the fire-protection walk, the evacuation time is determined by the width of the fire-protection walk.

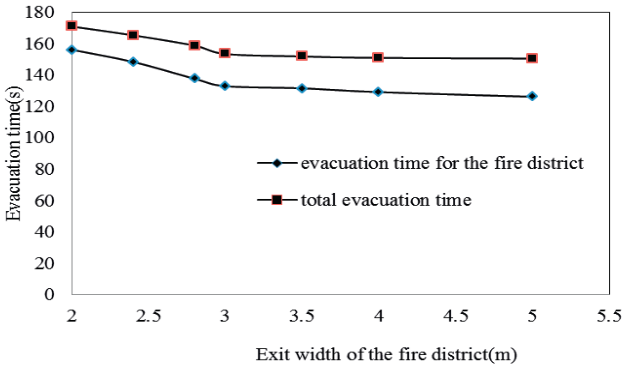

Fig. 2. Evacuation time of different width of exit of the fire district

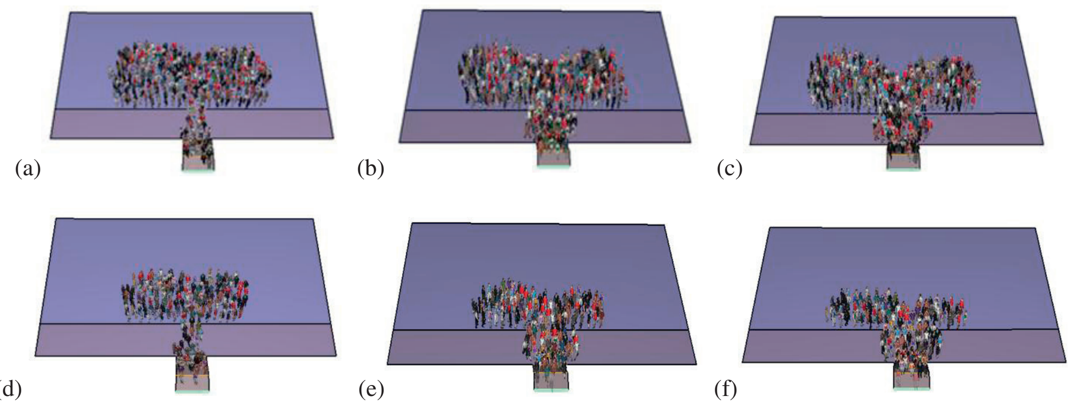

Fig. 3. Illustration of evacuation for (a) exit width is 2m, at 50s. (b) exit width is 3m, at 50s. (c) exit width is 4m, at 50s.(d) exit width is 2m, at 100s.(e) exit width is 3m, at 100s.(f) exit width is 4m, at 100s.

Fig. 3 shows the evacuation scenario when exit width is 2 m, 3 m and 4m at 50 s and 100 s. It is found that there is congestion occurred at the exit of the fire district. At this time, the key factors which affect the flow of people are the opening width of the exit toward to the fire-protection walk and the width of the fire-protection walk itself. Compared to cases of 3m and 4m, there are more people wait in front of the exit of the fire district when the width is 2m. As the width of the fire-protection walk itself was not changed in this case, the only effective factor is the width of the exit of the fire district. When its width is smaller than the width of the fire-protection walk, there must be more serious congestion. When its width is almost the same or wider than the width of the fire-protection walk, the largest capacity of evacuation is reached.

3.2. Walking distance in a fire-protection evacuation walk

The distance between the exit of the fire district and the entrance of the stair is the walking distance that people has to walk to a real safe place. In this case, the exit width of the fire district and the stair are 3m, the width of the fire-protection evacuation walk is 4m. The walking distance is set to4 m, 6 m, 8 m, 10 m, 12 m, 14 m, 16 m and 18 m. The evacuation time for escaping from the fire district and the whole evacuation time are list in table 2.

Table 2. Evacuation time in simulations of different walking distance in fire-protection walk

Walking distance (*m*)	Evacuation time for the fire district (s)	Total evacuation time (s)
4	132.8	153.3
6	129.4	153.5
8	125.4	153.7
10	124.5	155.1
12	124.4	157.3
14	122.5	165.5
16	123.3	176.2
18	122.1	183.3

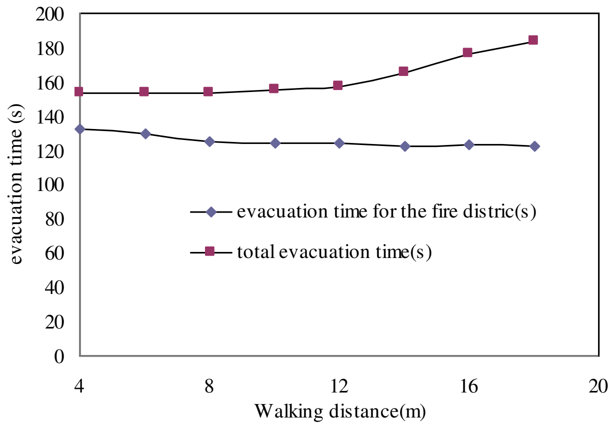

Fig. 4. Evacuation time of walk distance

It can be found that the evacuation time for the fire district does not change much as the walking distance changes. In this case, the exit width of the fire district and the fire-protection evacuation walk is more important than the walking distance is. But, the walking distance have great effects on the whole evacuation time. The whole evacuation time increased from 153 seconds to 183 seconds as the walking distance becomes longer. That means, although people may be safe in a fire-protection evacuation walk, it is a good design of not making people walk a long distance in the fire-protection evacuation walk.

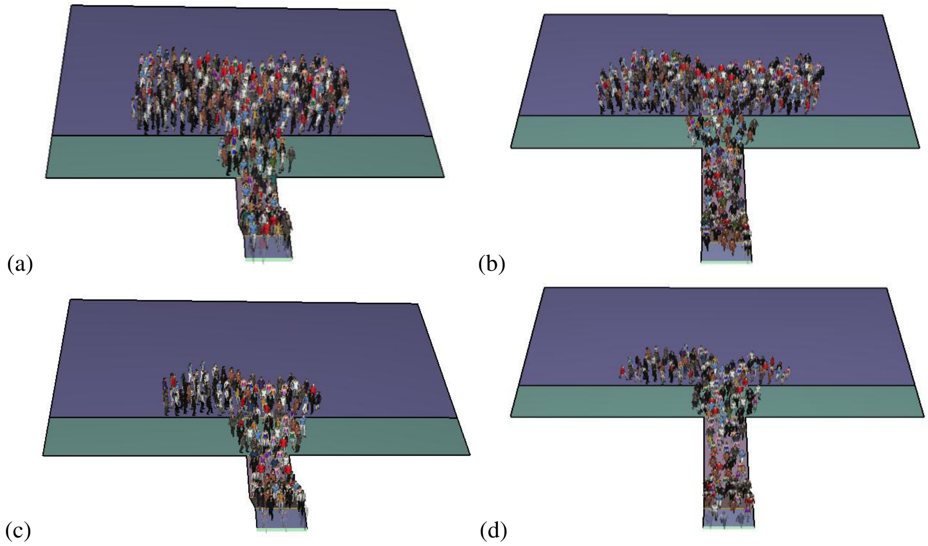

Fig. 5. Illustration of evacuation for (a) walking distance is 8m, at 50s. (b) walking distance is 12m, at 50s. (c) walking distance is 8m, at 50s.(d) walking distance is 12m, at 100s.

According to the simulation, for 8m and 12m fire-protection walk, the numbers of people passing though the exit of the fire district at the same time are almost the same. But, it takes more time for people to evacuate from the fire district to the stair. Compared to 8m, 30 seconds' more for safe evacuation when the walking distance is 18m. One problem is that there could be congestion occurring in a fire-protection evacuation walk if it has more than one entrance. So a short walking distance in a fire-protection evacuation walk can increase the evacuation efficiency.

3.3. The width of stairs

In this case, the width of stair were set to 2 m, 2.4 m, 2.8 m, 3 m, 3.4 m, 3.8 m and 4 m. Table 3 and Fig. 6 show the evacuation time for different stair width. The exit width of the fire district is 3m, the width of the fire-protection evacuation walk is 4m and the walking distance in the fire-protection evacuation walk is 4m.

Table 3. Evacuation time in simulations of different walking distance in fire-protection walk

Stair width(*m*)	Evacuation time for the fire district (s)	Total evacuation time (s)
2	195.6	222.3
2.4	170.1	197.3
2.8	147.6	172.5
3	132.8	153.3
3.4	124.7	145.6
3.8	109.2	132.3
4	106.4	121.3

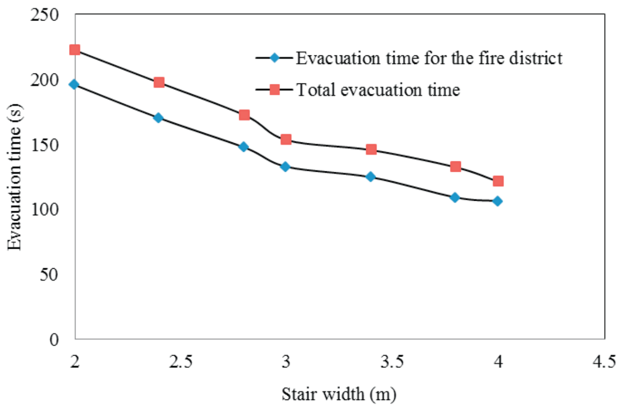

Fig. 6. Evacuation time of different stair width

It is very clear that a stair with wider width make people evacuate much faster. For this case, when the stair width is 2m, it takes 195.6 seconds to evacuate from the fire district and 222.3 seconds from the whole area, which are about 100 seconds longer than the stair width is 4m.

Fig. 6 shows that the stair width has great influence on evacuation time. Evacuation time decreases very fast as the stair width becomes wider. This is caused by congestion near the stair. Two reasons are responsible for the congestion. One is that the width of the fire-protection evacuation walk is 4m, which is wider than stair width. Another reason is that walking speed is lower when people walk on a stair than he walks on a flat ground. So, many people have to wait before they go into the stair. This makes the evacuation time becomes longer. Fig. 7 shows what was happened when stair width are 2m and 4m at 50s and 100s.

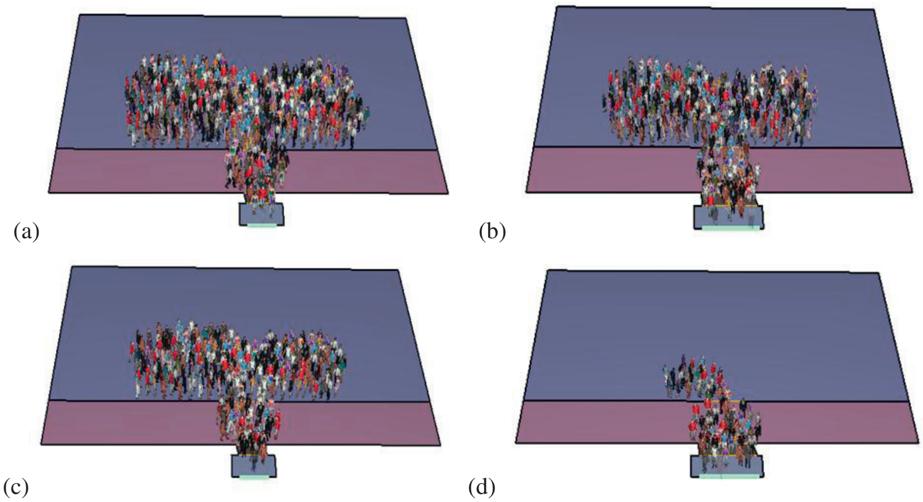

Fig. 7. Illustration of evacuation for (a) stair width is 2m, at 50s. (b) stair width is 4m, at 50s. (c) stair width is 2m, at 50s.(d) stair width is 4m, at 100s

At the 50 second, there is a serious congestion in front of the entrance of the stair when the stair width is 2m. Compared to the stair width is 4m, more people are waiting for going to the stair when the width is 2m. So, making the stair width moderately wider can evacuate more people at the same time.

4. Conclusions

According to the simulation results, the distance between exit of the fire district and the entrance of the stair leading to the out space (walking distance in a fire-protection evacuation walk), the exit width of the fire district and the stair leading to the out space are key factors that affect the evacuation ability of a fire-protection evacuation walk when the width of the fire-protection evacuation walk is determined.

When the exit width is almost the same or wider than the width of the fire-protection evacuation walk, the largest capacity of evacuation can be reached. Don't make people walk a long distance in the fire-protection evacuation walk and do not open too many doors towards to a fire district in a fire-protection evacuation walk. Otherwise, there will be congestions near these doors.

One important parameter is that it is good to set the stair and its entrance and exit width as wide as the fire-protection evacuation walk.

Acknowledgements

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